TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

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32 VICTORIA STREET
LONDON SW1

NOTES ON RECENT MEETINGS AND EVENTS

Meetings in London.

A meeting of the Society was held in the Lecture Theatre of the Institution of Mechanical Engineers (Storey's Gate, Westminster, S.W.1), on Tuesday, November 12. The chair was taken by the President (Mr. A. W. Beuttell) at 7 p.m.

The minutes of the last meeting having been taken as read, the names of applicants for membership were presented in the usual way.

The President then called upon Dr. R. J. Lythgoe to present his paper on "Visual Perceptions under Modern Conditions," which led to an interesting discussion in which the following took part: Sir John Herbert Parsons, Mr. C. C. Paterson, Wing Commander P. C. Livingston, Dr. J. W. T. Walsh, Mr. H. C. Weston, Mr. W. J. Jones, Mr. T. C. Angus, Dr. W. S. Stiles, Dr. G. P. Crowden, Mr. L. E. Buckell, Mr. R. R. Holmes, Mr. G. H. Wilson, Mr. J. M. Waldram, and Mr. R. O. Ackerley.

Dr. Lythgoe briefly replied to the discussion, and on the motion of the President a very cordial vote of thanks was accorded to him for his paper.

A subsequent meeting was held, also in the Lecture Theatre of the Institution of Mechanical Engineers, on Tuesday, December 10, when, in the unavoidable absence of the President, Mr. A. Cunnington (Vice-President) took the chair.

The minutes of the last meeting having been taken as read and names of new applicants for membership presented, the Vice-President called upon Mr. L. J. Davies to present his paper on "Practical Electric Discharge Lamps: Their General Applications and Recent Advances."

The paper was illustrated by many interesting experiments, and was followed by a discussion in which Mr. J. W. Ryde, Mr. C. R. Bicknell, Mr. W. Rule, Mr. W. J. Scott, and Mr. J. S. Dow took part. Mr. L. J. Davies briefly replied to the discussion, and a cordial vote of thanks for his paper terminated the proceedings.

An additional Joint Meeting with the Royal Photographic Society of Great Britain was held in their House at 35, Russell-square, London, at 6 p.m. on Tuesday, December 17, when Mr. R. G. Hopkinson's paper on "The Photographic Representation of Street Lighting Installations" was read.

The paper, which was illustrated by many photographs and diagrams, led to an informative discussion in which Mr. G. H. Wilson, Mr. F. C. Smith (for whom Mr. K. F. Sawyer deputised), Mr. J. M. Waldram, Mr. E. L. Damant, and Mr. A. W. Beuttell took part on behalf of the Illuminating Engineering Society and Mr. F. F. Renwick, Mr. O. Bloch, and Mr. E. R. Davies on behalf of the Royal Photographic Society.

Votes of thanks to Mr. Hopkinson for his paper and to the Royal Photographic Society for their hospitality were moved by the President and carried with acclamation.

Informal Meeting.

The Informal Meeting, the first of its kind, held at St. Ermin's Hotel (Westminster) on November 19, proved to be a great success. The proposition "That the User is the Ultimate Authority on Illumination," proposed by Mr. A. Cunnington and opposed by Mr. G. H. Wilson, led to an amusing debate in which the younger members of the Society took part. Mr. R. O. Ackerley's management of the meeting as Chairman contributed greatly to the pleasure of the evening.

Meeting in Manchester

On November 26 a meeting of the North Western Area Local Section took place in the Engineers' Club, Manchester. Mr. W. J. Jones delivered an address on "The Science of Seeing" which was illustrated by numerous lantern slides and demonstrations.

Applicants for Membership

(a) Elections Completed

The following names were presented at the meeting on Tuesday, November 12, and were read again at the subsequent meeting on December 10, 1935, when these applicants were formally declared members of the Society:—

SUSTAINING MEMBER:—

Messrs. James Jobling and Co., Ltd.....Wear Glass Works, SUNDERLAND.
(*Representative*:—Dr. D. Starkie.)

CORPORATE MEMBERS:—

Lucas, H. V.....29-30, Medway Street, LONDON, S.W.1.
Piper, H. F.....81, Hamilton Avenue, Tolworth, SURBITON.

COUNTRY MEMBERS:—

Fitton, J. W.....14, Kensington Grove, Timperley, CHESHIRE.
Sherry, W. G.....10, Marsden Street, MANCHESTER.

ASSOCIATE:—

Wiles, W. G.....13, Addiscombe Grove. CROYDON.

At the meeting on November 12 the names of those announced on October 8, which have already been published ("Illuminating Engineer," Nov., 1935, p. 358), were also read again and the elections duly completed.

(b) Elections Initiated.

At the meeting held on Tuesday, December 10, 1935, the following names of applicants were read for the first time:—

CORPORATE MEMBERS:—

Lythgoe, Dr. R. J.....University College, Gower Street, LONDON, W.C.1.
Alderman, J.....Automatic Electric Company, MANCHESTER.

COUNTRY MEMBER:—

Page, M. B.....231, Produce Exchange, MANCHESTER.

AFFILIATED STUDENT:—

Mogford, G. S. H.....12, Chilmark Road, Streatham Dale, LONDON, S.W.16.

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VISUAL PERCEPTIONS UNDER MODERN CONDITIONS

By R. J. LYTHGOE, M.A., M.D., D.Sc.

(Paper read at the Meeting of the Illuminating Engineering Society, held at the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, London, S.W.1, on Tuesday, November 12th, 1935.)

SUMMARY

The paper describes how certain topical problems of practical illumination strike a physiologist. Controlled investigations on the level of illumination, on the general illumination and on glare are described. The evidence is, on the whole, in favour of a high illumination without extremes of contrast. It is easy to find experimental evidence of improvement in vision when the illumination is raised to high values or when the worst forms of glare are eliminated. Modern practice aims at an illumination giving low contrast and with a minimum of glare. It may not be possible to justify the practice on experimental grounds but general considerations are in its favour. When contrasts are small the eye demands a higher general level of illumination than when strong contrasts are present. Although it is convenient to separate quantity and quality of light in controlled investigations there is probably a biological link between them. Some aspects of the colour of artificial illuminants are considered.

Introduction.

Those whose work is the investigation of the problems of sight are forced to remember that the eye cannot be described merely as an exceedingly complex physical instrument. The eye can, in fact, perform half a dozen difficult operations simultaneously and can generally perform them very much better than the best physical instruments occupying many cubic yards of space. It is, however, of the first importance to remember that the eye is a living structure and that simple optical reasoning and arguments may be invalid when applied to it.

What do we mean when we say that we can see an object? We mean that we gain some idea of its size, its distance from us, its colour, the lights and shadows on its surfaces and the details of its construction. If the intensity of illumination falling on the object be increased then it is probable that we shall say that we can see the object better, but a more critical analysis may reveal that although most of the features of the object are more readily appreciated, others such as the distribution of light and shade are less easily appreciated. The act of seeing involves many factors and the influence of illumination must be studied on each separately. In this way only can we attempt any numerical classification of the goodness of seeing, and incidentally it forms the basis of Beuttell's most interesting method. Good sight is as impossible to measure as good health; we can only measure factors of each such, for example, as the minimum resolution angle of the one, or again, the muscular power of the other.

The eye differs from many physical instruments in being very particular about the surrounding conditions. Suppose one wishes to get the best view of an object with a given amount of light; it is usually inadvisable to concentrate all the light on the object leaving the surrounding field of vision dark. This is very different from the state of affairs in photomicrography, for instance, where the best result is obtained when light is rigidly excluded from all outside sources. With visual observation down a microscope things are otherwise; here it is a mistake to turn out the lights in the room so as to produce a light field in black surrounds. Not only would the visual conditions be less comfortable but they would not be good for the recognition of detail, etc. We may anticipate matters by saying that the eye works best when the object regarded is surrounded by a field of vision illuminated to the same extent or slightly less than itself. It must be stated emphatically, however, that with the surrounding field brighter than the object regarded, we have very bad visual conditions. Finally, there is a very important special case of the illumination in the surrounding field of vision; I refer to glare from concentrated light sources. Although usually producing deleterious effects on vision and acting like an overbright surrounding field, glare sometimes improves visual perception so acting in the same way as a moderately illuminated surrounding field. We shall see later that there is a growing recognition of the importance of good general illumination in the workshop, office, etc. As a physiologist, I would certainly support this view. The eye can function over a wide range of illuminations, from about 0.00001 foot-candles to 10,000 foot-candles, but in order to do so, it demands that the ratios of brightnesses in the field of vision shall not be too great. In technical language it is said that the eye must be adapted to the general prevailing brightness in order to work at its best.

Let us sum up the present-day attitude to the illumination requirements of the eye. In devising a system of illumination, we must first take into account the character of the visual task. This will determine the type and level of illumination on the task itself. Next we must make sure that the general illumination is good, both by the elimination of heavy shadows and of glaring sources. In the following part of this paper I propose to say something of the theoretical evidence on which are based our ideas of good illumination.

The Level of Illumination.

Visual Acuity.

Let us first consider the influence of the level of illumination on visual acuity. Now visual acuity is measured in terms of the smallest detail which can be resolved by the eye. In practice the recognition of letters or some similar task is employed. When

interpreting graphs it is often helpful to remember that the figure given for visual acuity is also the distance from the eye in metres at which a letter 1.45 mm. high can be read. Laboratory experiments show that the acuteness of vision becomes progressively better up to 1,200 foot-candles. (Fig. 1, upper

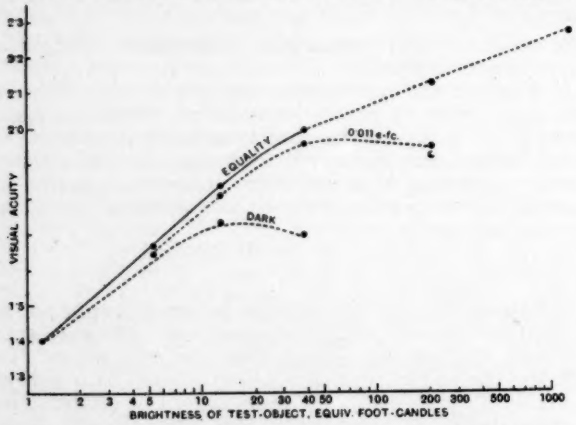

Fig. 1. The relation between visual acuity and illumination at different brightnesses of the surrounds (values printed on curves). This and other figures taken from M.R.C. Spec. Rep. 173.

curve.) In commercial occupations like type-setting one would expect, and does in fact find, that the performance improves up to high levels of illumination (Weston, 1927, etc.). It is sometimes stated that visual acuity for detail does not improve much above 3 foot-candles. The reason for this belief is interesting (Fig. 2) and is based on the fact that with

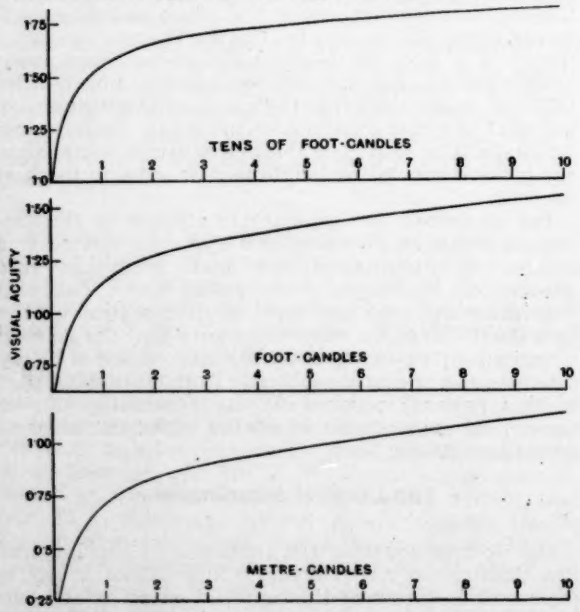

Fig. 2

a linear scale of illumination the improvement apparently becomes less marked above 3 foot-candles; if you happen to work in metre-candles and draw a similar graph you will be surprised to find that improvement in visual acuity apparently becomes negligible above 3 metre-candles. The reason for this is that visual acuity, measured by the distance at which the 1.45 mm. letter can be read, is proportional to the logarithm of the illumination. Put in other words, a tenfold increase in the illumination adds 0.6 metres to the distance at which the letter can be read. Drawn on a logarithmic scale of illuminations, it is obvious that the highest visual acuity has not yet been reached by artificial illumination, whilst there are indications that higher values still are attained in the very bright lights of out-of-doors. It must be strongly emphasised, however, that successive doublings or treblings of the illumination lead only to equal arithmetic increments of visual acuity or the distance at which a standard letter can be read; whilst at illuminations above 10 foot-candles we get progressively less than our equal arithmetic increment. In occupations such as are usually found in industry where there is a large non-visual element, we should not expect to find that the improvement with illumination is anything like so marked. As the illumination is increased above a certain value, a lighting installation must be judged more on general grounds than on performance. The increased cost of high illuminations may be out of all proportion to the material benefits. More can be got from attention to other details such as the provision of spectacles in suitable cases.

Differences of Brightness.

The recognition of small differences of contrast behaves in a different manner with increasing illumination. I do not wish to enter into details, but the gist of the matter as revealed by recent work on the difference-threshold is as follows. If we have a piece of grey card covered with areas of a darker grey, with no surface texture, then the recognition of those areas and the differences of brightness between them is at its best when the brightness of the card is in the region of 3 equivalent foot-candles. If more or much less light falls on the card then the differences in grey become less obvious. I was contemplating a concrete house recently. To the naked eye in the bright sunlight the walls appeared quite smooth and uniformly white, yet in the evening the walls of the house appeared to be covered with areas of light and shade. The sun was too intense for the best view of these areas of light and shade on the walls, but perception in the lower brightness of evening light was much better.

If we mix the two types of perception involved in the recognition of detail and in the recognition of contrast by making our task the recognition of small grey letters on a background of another grey, we find that perception again improves up to high illuminations. Indeed, it is found that even, with a correction made for the grey of the letters, the perception of detail of low contrast requires a higher brightness than for the perception of black on white. We can say, there-

fore, that for the majority of everyday tasks, such as the recognition of pedestrians by street lighting, or let us say of rust on a casting, the higher the illumination the better, in the range so far explored. For a few specialised tasks such as the recognition of areas of stain on lengths of cloth, the brightness should not exceed 3 equivalent foot-candles.

A recent survey by the Service Bureau of the Electric Light Manufacturers' Association has shown that, given a free choice, most people prefer an illumination for reading in the region of 100 foot-candles. This result accords with one's personal observation that people are using higher and higher illuminations. I think it is probable that the limit to the demand is set by the condition of the surrounding illumination: when this is high the eye will demand a high illumination on the book.

Industrial Processes.

During the last few years there has been some outstanding work on the effects of illumination on certain industrial processes. From the figures there quoted, one can read the factory output at different degrees of illumination. If it is possible to obtain such figures in the few industries investigated, it should be possible to obtain them for all industries. It would then be possible to give figures showing the output at any level of illumination, and the cost of running the lighting installation—a lengthy job, but once done is good for all time. Such experiments are, however, long and very difficult; intercurrent conditions in the workshop may render all the work which has gone before useless. Even in industrial occupations where illumination has a considerable effect on output one finds that the mean error of the results does not admit of precise recommendations. Where the type and quality of the illumination have only a small effect on output, it would be quite hopeless to attempt an experimental investigation in the workshop. In such cases one is forced back on laboratory work where conditions can be controlled much more rigidly and the investigation can be carried out uninterruptedly for many years if necessary.

Investigations in industry have confirmed that where fine work is concerned the level of illumination can be raised with benefit to tens of foot-candles, and it is probable that a further improvement would result from an increase to 100 foot-candles, or more. A critical survey of the work of J. Ives (1926), Weston and others is not possible, but I must mention the recent paper by Adams on Tile Pressing. The latter is an occupation apparently calling for only the crudest visual perception, and, apart from carrying the tiles to and from the machine, merely involves putting the tile in the machine, pressing it, and withdrawing it again—a task which could be done blindfold. The remarkable result from this work is that the performance was very materially speeded up by an increase of illumination from 0.6 to 14.3 foot-candles. Can the explanation lie in the speed of vision? Are all our movements slowed down at night under feeble illumination? It is a point which could be settled by direct experiment.

The results of other laboratory experiments on speed of vision and so forth show that there is a continuous improvement in visual performance certainly up to 130 foot-candles (Cobb, 1925), but there is no time to consider them in detail. We will pass on to consider a condition which makes for good illumination, namely, the general illumination of the room as distinct from the illumination of the piece of work itself.

The General Illumination.

Laboratory Work.

A short time ago we noted that the acuteness of vision improves up to high illuminations. This statement must be qualified, however, since it is true only when the surrounding field of vision is adequately illuminated. If the surrounding field of vision is completely dark (lower curve of Fig. 1) the acuteness of vision begins to fall off when the illumination is raised above 10 foot-candles. With a surrounding field of 0.011 equivalent foot-candles, acuity begins to fall off above 40 equivalent foot-candles (Fig. 1). Fig. 3 shows how with a constant

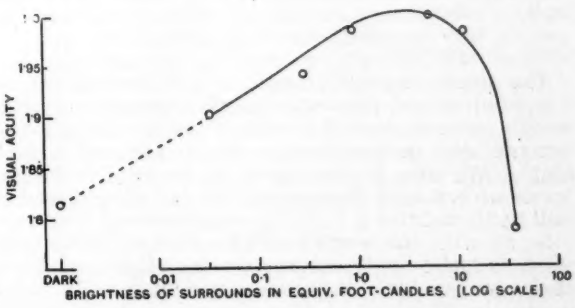

Fig. 3

illumination of the test-object at 13 foot-candles, the visual acuity improves slowly as the surrounding illumination is raised to the level of that of the test-object or a little below. When the surrounding illumination is raised above this point there is a very rapid falling off in performance. This result appears to apply to most visual functions which have been investigated. For instance, both the perception of contrast (Cobb, 1916) and the perception of flicker (Lythgoe and Tansley) improve slowly as the brightness of the surrounds is raised to that of the test-patch and then they fall off rapidly.

The Adaptation of the Eye.

One of the most striking peculiarities of the eye is its power of adaptation. This does not mean only the dark adaptation to feeble illumination, but adaptation to the general prevailing illumination, whether this be one or ten thousand foot-candles. The eye works well under a wide range of illumination, but to expect it to work at one brightness when it is adapted to another much higher or lower brightness is like using an ammeter with the wrong shunt in circuit. This explains why the natural illumination

of daylight is so satisfactory; there are no great differences of contrast. Indoors with artificial illumination there are considerable differences of contrast. Every photographer knows that the negative of an interior has to be developed for a shorter time than that of a landscape. The short development softens contrasts, which are usually present indoors. Out-of-doors contrasts are rarely greater than 40 to 1. I believe it to be a sound principle of good lighting that there should not be great differences of brightness between the task and the surrounding field of vision, neither should there be areas of high or low brightness within the surrounding field itself. I believe this to be true both on general principles and on detailed laboratory work. We should never allow the surrounds to become brighter than the work itself, and when the problem is the illumination of dark objects such as dark woven materials it is advisable to have slightly darker walls (measured objectively). Naturally, one would not suggest painting the walls black; a much more economical solution would be the provision of local lighting to bring the brightness of the cloth up to or above that of the wall.

Dark Adaptation.

The phenomenon of adaptation to darkness is familiar to all of us; for instance, after being in an artificially lighted interior it takes a measurable time to become used to the exterior illumination of a dark night. We may confidently look forward to higher levels of artificial illumination in the future, and it will be thoughtful if lighting engineers will then provide us with moderately illuminated corridors and stairs to make the transition easier. After the setting of the sun in these latitudes, daylight usually fades gradually. If, however, for some reason the illumination falls quickly, the eye does not adapt to the darkness rapidly enough to follow the process; the world seems darker than it really is, and there is a rush for the light switch. The level of artificial illumination provided may not be very high, and almost certainly only a small fraction of the daylight illumination. As a result the lighting of our room still seems too low. I suggest that the result is explained not in terms of the incompatability of day and artificial light, but in terms of the adaptation of the eye.

The Discomfort of Contrast.

Extremes of contrast are subjectively uncomfortable. A large expanse of black in the field of vision may in some respects affect one in the same sort of way as a glaring light source; both produce uncomfortable distractions, but the ill-effects may not be measurable by any known test.

Industrial Processes.

Apart from some work on the weaving of fine linen (Weston, 1922) there are very few detailed figures for the effects of general illumination on output in industrial life. Weston found that a change over from daylight to artificial lighting resulted in an 11 per cent. reduction in efficiency. This drop was attributed to shadow effects and the absence of general illumination rather than to the amount of illumination. Judging by the difficulty of getting clear-cut results of the effect of general illumination in the laboratory, I am doubtful whether convincing results will be obtained in the workshop for many years to come. Many of the unpleasant effects of bad general illumination can be judged only in terms of discomfort. It is not possible to give a simple theoretical explanation of one's belief in good general illumination. This sort of thing is one of the difficulties of biological science. Fresh air undoubtedly maintains better health than the air of ordinary rooms, but the explanation is not easy to find.

Closely Observed Objects.

Sudden changes in the field of vision instantly attract one's attention; e.g., a movement seen out of the corner of one's eye by oblique vision or the switching on of a light in a house when one is outside. Similarly, flickering illumination of 10 cycles a second is most unpleasant, because of the repeated and sudden changes. A neon discharge tube fed by alternating current is unpleasant, because when its image moves across the retina, due to eye movements, the image consists of a series of bars where we instinctively expect uniform motion. If we gaze at a dark object in light surrounds the first movement of the eye is apt to produce unpleasant after-images bordering the object. When the conditions involve looking at a limited area for long intervals I should favour the provision of a surround not too different in brightness from the object itself. In this way these after-images, these sudden and startling messages, can be largely avoided. This sort of argument would apply to the hanging of pictures, the staging of a bright tableau on the stage or the surrounds of the screen at the cinema, although there are complicating factors in the latter. I should be in favour of a surround somewhere in the region of a quarter that of the mean brightness of the tableau.

Glare.

Laboratory Work.

The presence of a single source of light in the field of view can produce effects similar to generally illuminated surrounds. A single glaring source of light hanging on a black wall near a visual test-object may actually improve perception of the test-object, provided the candle-power of the glaring source is not too high. This result is due partly to a constriction of the pupil and partly to some improvement in the retinal mechanism of perception. If, however, we have a very powerful source of glare, then there is a depression of all visual functions. The various classes of visual perception behave differently in this respect. For instance, the perception of contrast invariably tends to be worse in the presence of glare (many workers, including Stiles, 1929), whilst the acuteness of vision for fine detail is often improved. When the task is the recognition of low contrast detail, the deleterious effect of glare is predominant and the performance is lowered in the presence of glare. By far the most satisfactory method of considering glare is that developed in recent years, especially by Stiles. Essentially the method is to find a brightness which, when

spread over the whole visual field, will produce the same effect as the glare itself. Imagine, if you like, that you are looking through a sheet of glass, from one of whose surfaces light is being generally reflected.

The Action of Glare.

Glare is evaluated in the above manner because it is thought that many of its effects are due to a scattering of light within the eye; but glare has two other major effects, viz., it alters the general level of adaptation of the eye and it produces a feeling of discomfort. The alteration in the level of adaptation of the eye, that is, the sensitivity level of the retina, can be measured physiologically, although not much work has been done on this aspect.

The phenomenon of discomfort is probably the most serious ill-effect of glare and has to be studied psychologically, relying entirely on the subject's verdict as to what is unpleasant or not. In this type of experiment (Nutting, Luckiesh, and Holladay, 1925) a large white screen is used whose brightness can be varied. At some point in this screen a glare source is arranged with variable intensity and area. The intensity, area, and position of the source are then varied until the person looking at the screen says that a definitely unpleasant limit has been reached. Another method recently developed by Luckiesh and Moss (1933) is the measurement, under unfavourable lighting conditions, of the involuntary contractions of the hand muscles, or the nervous muscular tension as it is called by the authors. I think we should be guarded in our interpretation of the results, because physiological reactions to psychological conditions (e.g., the psycho-galvanic reflex) do not as a rule lead to reliable results.

Apart from the relatively minor effects of after-images and changes in pupil diameter, glare does three things: it produces a physical scattering of light within the eye; a physiological alteration in the level of adaptation; and a psychological feeling of discomfort. All are evil except the occasional shift of retinal sensitivity in the right direction by a single source of light in otherwise dark surrounds.

Colour and the Eye.

The eye has great powers of adaptation, and there are two points in the perception of colour which illustrate this very clearly. In the first place we can become adapted to the predominant wave-length. Everyone knows the familiar experiment in which two pieces of white paper are illuminated, one by daylight and the other by the light from electric bulbs. When these two pieces of paper are viewed side by side in an otherwise dark room, the paper illuminated by daylight looks a decided blue, the other a decided yellow. Seen without comparison the paper looks white under a wide range of dominant wave-lengths. The eye can become adapted. In the second place the eye as an optical instrument is uncorrected for chromatic aberration and there must also be considerable circles of diffusion due to other aberrations. Nevertheless, to the normal eye a point source of light seen in daylight looks like a point source; there are no colour fringes around it. The eye makes allowances for these fringes and they do not appear in consciousness under normal conditions. If, however, we look at the point source through a cobalt glass which passes extreme wave-lengths, then we may see a red central area with a blue halo or vice versa.

Gaseous Discharge Lamps.

In the early type of lamps, the emission was very close to the ordinary line spectrum of the metal. With mercury vapour there is a considerable difference in wave-lengths between the yellow lines at 0.579 μ and the blue at 0.436 μ. The eye cannot focus on both these wave-lengths simultaneously. I calculate that their images are about 0.13 mm. apart, or, again, if the eye was focusing one line it would need the addition of a one-third Dioptre spectacle lens to the eye in order to focus the other. An error of astigmatism of $\frac{1}{2}$ Dioptre will sometimes lead to symptoms such as severe headaches, and these symptoms are often attributed to the difficulty of finding the correct focus or accommodation of the eye. It is just possible that the one-third Dioptre difference in the focusing power necessary between the yellow and blue lines of the mercury spectrum will produce symptoms. With the newer types of lamp which give an almost continuous spectrum I doubt whether symptoms will arise. Nor do I think that the difference in dominant wave-lengths between daylight and ordinary forms of artificial light is sufficient to call for a different degree of accommodation for each.

Blue Light and Visual Perception.

Finer visual judgments are not equally good in light of different wave-lengths. If the eye behaved as a man-made physical instrument, its performance with blue light would be better than at any other wave-length. As a matter of fact, the eye behaves worst in blue light; its perception of contrast, its acuteness of vision, and other functions are relatively bad. This phenomenon cannot be discussed in physical terms; it is a physiological phenomenon depending on the fact that certain elements of the retina are used more for the perception of blue than they are for other colours, and these elements, although they are stimulated by small quantities of light, are relatively poor in the performance of the finer visual judgments compared with the other set of elements which are predominantly stimulated by other wave-lengths.

Daylight and Artificial Light.

Although daylight is bluer than the artificial light of a gas-filled lamp, I do not think that there is nearly enough difference to make visual acuity, etc., worse in daylight. Experiments have not revealed any significant difference. Dow (1928) asks why it is that artificial light appears brighter than fading daylight of the same objective brightness. I do not think that the phenomenon is due to any of the colour effects mentioned above. One thing is, I think, significant. In making a visual comparison between a room lighted by single suspended units

and a room lighted by a large ceiling panel, most people would say that the ceiling panel gave a lower illumination, although the objective brightnesses were identical. I would suggest the tentative explanation that the eye judges the level of brightness by the brightest object in view. It is probable that an area of high brightness raises the adaptation level of the whole retina more than a correspondingly low area of brightness depresses it. In our three examples, the suspended unit will be brighter than the ceiling panel and this brighter than the sky; we would place the illuminations in that order by observation but by instrumental test we might find them all three alike. A blameless installation of artificial light is apt to appear dull; not only does the lighting seem featureless, but it also appears to be of too low an intensity.

The Basic Qualities of Natural Illumination.

I think that the various aspects of good artificial illumination can be brought into relation with one another. We can do this by passing in easy stages from the most evil type of artificial illumination to the best type of illumination which is found out-of-doors. Let us imagine a room with black walls. In the centre is a lathe illuminated by a single 60 w. clear bulb on the ceiling hung so as to shine into the worker's eyes. Everything is wrong with this system, glare, specular reflection, insufficient illumination and too great a contrast between the work and the surrounding field of vision. If a pearl is substituted for a clear bulb, then we can partially eliminate those troublesome after-images. The next step will be to paint the walls a grey so as to give them a brightness a little below that of the work of the lathe. This step will eliminate excessive difference in brightness between the work and the surrounds, and will cut out some specular reflection. Our next step is somewhat unorthodox; instead of having a single pearl lamp, we cover the ceiling with lamps a few inches apart. One might think that if one lamp produces "A" units of glare, 500 lamps would produce 500 "A" units of glare, but in point of fact glare would have vanished, and we should have passed from an illumination of two foot-candles, let us say, to one of some 700 foot-candles. I was much struck in Russia by the illumination systems. In the Dietskoye-Selo, Leningrad, there were about 4,000 candle-type bulbs distributed over the walls, whilst in the Grand Palace of the Kremlin many large candelabras were suspended, each containing 400 lighting units. This principal of illumination is also much in favour in the new Moscow Metro. We need not go so far as Russia to see an example of illumination by a large area of approximately uniform brightness. Out-of-doors illumination on a cloudy day gives us an example except that the level of illumination may be several thousand foot-candles.

A rough and ready way of considering glare is in terms of the degree of contrast between the source of light and the rest of the field of vision. Waldram has an instructive example of this principle in daylight illumination through windows. Here it is not so much the level of illumination falling on the work bench which counts but the ratio of bright sky to the comparative darkness of the rest of the visual surrounds. Increase the window area and the discomfort vanishes. A single lamp or a small window leads to excessive contrasts. With many lamps, or out-of-doors on a cloudy day or with large windows, contrasts are no longer present. We may notice in passing that the illumination by the sun on a cloudless day is hardly in accord with the views of the illuminating engineer who would certainly not consider the illumination of an area the size of half the world by a single unshielded source of light.

The illumination out-of-doors in summer, when light clouds obscure the sun, is in the region of 5,000 foot-candles. The illumination produced by a lighted ceiling panel may be as low as 5 foot-candles without exciting notice. Between these limits of five and 5,000 foot-candles it is extremely difficult to judge the absolute level of illumination. If, for instance, I had guessed that a certain illumination were 500 foot-candles it would not surprise me much to learn that it was only 100 foot-candles. The eye is as particular about quality as it is about quantity. As the illumination is increased from 5 to 1,000 foot-candles there is a steady definite increase in all visual tasks with the exception of the perception of differences of brightness. Visual acuity, quickness of vision, colour perception, etc., probably improve slightly from 1,000 foot-candles to 10,000 foot-candles. The real upper limit to artificial illumination for the majority of tasks is set not by any property of the eye as yet discovered but by considerations of economy, and, let us add, heat. I suppose there is no place demanding better visual conditions than the hospital operating theatre; here we find very high levels of illumination are recommended and used (Beuttell, 1934), whilst the accompanying warmth is no disadvantage. Where high illumination can be got for nothing we find those engaged in fine work deliberately choosing it, as, for example, the lace workers at Geneva, who take their fabrics into the bright sun.

The general increase in the standards of artificial illumination is in keeping with the more generous economic outlook of to-day. Wages are higher than at the beginning of the century, the level of living has been raised; along with this there has been an increase in level of illumination of factories. It is obvious that even to-day the standard is going up, and the minimum recommendations are constantly being revised. Where before the war four foot-candles was the recommended minimum, the minimum to-day is ten foot-candles. There are few people left who say that ten foot-candles indoors is too high, but who take their holidays fishing in 10,000 foot-candles. So far as the experimental evidence goes, the real limit to the level of artificial illumination must be an economic and technical problem. We must never forget, however, that the true skill in this, as in all things, lies in making a little go a long way. Anyone can take a snapshot of a child out-of-doors in 5,000 foot-candles, but skill is required in the disposition of the lights to produce a pleasant portrait indoors with 100 foot-candles only. In the same way skill is required in the lighting of certain types of dark woven

materials. The engineer has to strike the best balance between brightness level, absence of glare and contrast, and a reasonable amount of unidirectional lighting to show up the threads.

There are well-defined medical conditions due to the very high brightnesses found in deserts. If one listens to the catalogue of vague complaints of persons who think that the existing level of artificial illumination is too high, one is struck at once by the fact that the symptoms are not the same as those due to really high illumination. My own view is that the explanation of the symptoms alleged to be due to ordinary types of artificial illumination is not to be found in terms of the illumination itself.

I am conscious that I have dealt with the problems of illumination in general terms, which are not immediately helpful to the practical man. A great deal of excellent work has not been dealt with, but I must plead the limitations of space and time. The practising engineer has the most difficult task, since he must work to exact details. My own view, however, is that, provided the general principles were understood, each case as it arises could be settled on its own merits.

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DISCUSSION

Sir JOHN H. PARSONS, remarking that the paper demonstrated in a striking manner the advance that had been made in the study of lighting since the days when he was President of the Society, said he had often told biologists who were interested in visual problems that the greatest advances made in physiological optics during recent years had been due to the physicists. Much of their work was liable to be missed by the biologist. One of the difficulties was that the biologist was not mathematically minded, and had difficulty in interpreting graphs and logarithms. One great function of the Society was to popularise the scientific aspects of the subject, and the paper was an admirable attempt to do this. The cardinal principle of the Society since its inception had been that every aspect of illumination should be explored, including the physiological, the psychological, and the aesthetic. At the same time, the fact that the physiological side was not being neglected was not altogether due to the Society. It was also due to the fact that there were a large number of problems such as street lighting and the lighting of aerodromes in which the physicist found there was something to be learned that was outside his province, and without assistance from the physiologist he could not get on with the problem at all. Many of these problems were extremely complicated, and were not solved by attention directed to only one factor, such as visual acuity. Visual efficiency depended upon what he had termed " visual capacity," i.e., visual perception as a whole, which involved the interaction of various factors. The author had exemplified in an admirable manner that too much stress was often laid on individual features of the various physiological performances of the eye and certainly far too much stress was laid on visual acuity as the sole standard of visual ability. Defective visual acuity under certain conditions might be to a large extent compensated by other factors. Thus these physiological problems were of the utmost complexity, and the author had done well to call attention to them in the manner he had.

Mr. C. C. PATERSON expressed satisfaction that attention had been called to the importance of general field brightness in any scheme of illumination, and also to the fact that it was often necessary not to rely upon experimental results but to fall back on common sense. It was an unfortunate thing, however, that very often industrialists found it difficult to do this, and insisted upon experimental proof in every case. In connection with the improved lighting mentioned in the case of tile pressing, the author did not appear to have placed weight upon the general psychological effect, in that under better lighting conditions people seemed more ready to exert themselves, quite apart from the ability to see better. The paper referred to gaseous discharge lamps, and suggested there was a tendency for a great deal of blue light to be emitted, and physiological reasons were given why on this account these lamps might not have the advantages which might appear at first sight. Surely, however, the author was wrong in his facts. A spectral examination shows that there is

not a lot of emission of blue radiation in these lamps. (This point was illustrated by lantern slides; Figs. 1 and 2.) Probably the author thought these lamps emitted in the blue part of the spectrum because they looked blue, but if they were examined carefully it would be seen that the dominant colours were green and yellow. Possibly the lamps looked blue because there was an absence of red. He mentioned this, said Mr. Paterson, because there might be people who would draw wrong conclusions from what the author had said.

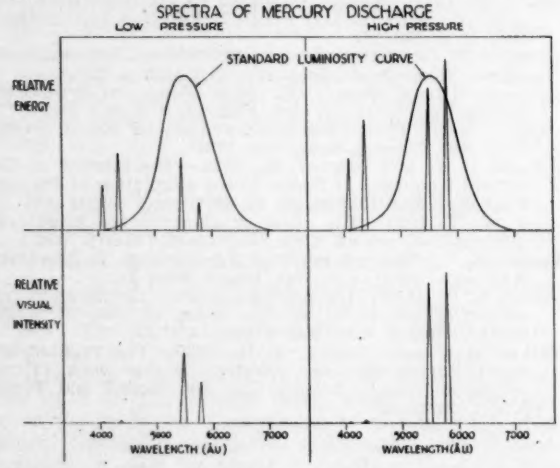

Fig. 1

DISTRIBUTION OF LUMINOUS INTENSITY IN THE SPECTRUM OF THE HIGH PRESSURE MERCURY DISCHARGE.

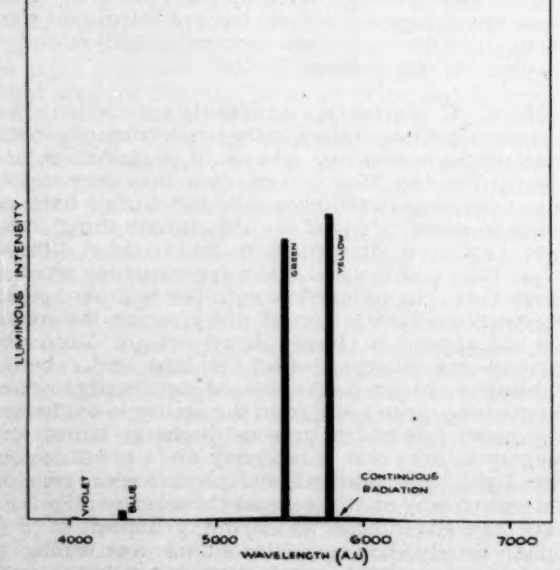

Fig. 2

At the end of the paper the author had spoken of the possibility of still further increasing artificial illumination to the degree of daylight, and referred to it as an economic and technical problem. Personally, he was wondering whether it was not physiological, because such a degree of illumination could not be tolerated locally, leaving the remainder of the surroundings at lower levels. The contrast would be too high. What really determined this question was again the characteristics of the eye. If the range of illumination over the field was made too great there would be trouble. Therefore, the range of brightness the eye was asked to cope with must be adjusted to the extent which a given adaptation of the eye permitted one to use, and no more.

Wing-Commander P. C. LIVINGSTON (Medical Research Council Committee on Vision) said he had been concerned with the lighting of aeroplane cockpits and the illumination of aeroplanes and aerodromes for the purpose of night flying and landing in such places as Mesopotamia, where there was also the problems of sun glare to contend with. When he first went out there he found the conditions of artificial lighting in the buildings where the staff had to work—and they worked by artificial lighting practically all the time—were appalling, and it took quite a long time to get these improved. The lamps were about nine and a half feet from the faces of the men who were keeping accounts and doing similar work, and the lamps were also covered with dust.

However, things were very much better in that respect now. In dealing with night flying and night landing much work still remained to be done before ideal conditions could be attained. Illumination producing strong glare was bad under whatever circumstances such illumination was employed. It resulted in both visual fatigue and in fatigue of the muscles which governed the movement of the eyes. This was an important point in connection with industrial lighting, as it undoubtedly affected man-hours and man-production. That had been brought home to him in a striking manner in connection with two factories which medical colleagues once asked him to investigate from the ocular muscle balance point of view. He worked in those factories for several months, and definitely ascertained that reduction in production per man was produced by reason of this type of fatigue. A small adjustment in the lighting arrangements made a considerable difference in the comfort of the workers and in their output. There must be an optimum in each particular instance when the lighting is sufficient, evenly distributed, and comfortable, without causing ocular fatigues, owing to the necessity of undue concentration on the one hand, and glare on the other.

Dr. J. W. T. WALSH asked if anything had been done to determine the scale of brightness which corresponded to the general impression of the man in the street on similar lines to what was being done in connection with sound. Sound engineers had a scale of increases in decibels, and this was really a

logarithmic scale. It was the fact that an increase of so many decibels at a low level of sound did not appear to the man in the street as at all the same thing as an increase by the same number of decibels at a higher loudness level, and he was wondering whether anything of the same kind happened in illumination and whether illumination engineers had met with the same difficulty. For instance, the man in the street might not regard a 20 per cent. contrast at one foot-candle as the same thing as 20 per cent. contrast at 100 foot-candles, and if there was any useful information available with regard to this it would be extremely valuable. Further, he would like to ask whether there was any information available as to the time a motor-car driver would take to adjust himself to the altered conditions when going from a brilliantly lighted main street into a side street where the illumination, by contrast, was practically zero.

Mr. H. C. Weston (Industrial Health Research Board), referring to glare, said he not infrequently found a factory occupier, seeing reflectors had been deliberately removed by the workers, came to the conclusion that glare was of no great importance. Surely, however, the fact that reflectors had been removed was an indication of insufficient lighting. The effects mentioned in the paper in connection with the tile pressing works he regarded as very largely psychological. The original illumination of these tile pressing works was appalling, as all daylight was excluded and the only illumination came from one or two bare vacuum lamps which were in a very bad condition. It was impossible to think that workers could feel very cheerful or very much inclined to work under such conditions.

Mr. W. J. Jones expressed the view that the author had done a signal service in stressing so strongly the important question of contrast, and it was to be hoped that those who knew the public taste in, and demand for, higher standards of illumination would ensure that the surroundings were satisfactorily lighted. It had been mentioned that visual acuity by itself was not necessarily a satisfactory index of one's ability to see in different standards of illumination, and that it was necessary to take into consideration the general characteristics of the eye. He would ask Dr. Lythgoe to what extent were we able to see better in 100 foot-candle than in 1 foot-candle, speaking in general terms and not in visual acuity? Could he also tell us how much the eye was impaired with low values of illumination and how much more fatigue was introduced under these conditions? The Society would be doing an excellent service if it could inspire the physiologist to take an even greater interest in the inter-action between lighting values and the physiological reactions of the eye, and, indeed, the body as a whole.

Mr. Jones then showed some lantern slides. The first (Fig. 1) showed the result of recent work on some 800 subjects, and represented the results of people's preference for illumination values when reading an ordinary daily newspaper. Another investigation related to the selection of illumination values by people of varying ages and confirmed, what every oculist knew, that people of advancing years required more illumination than younger people. The second (Fig. 2)

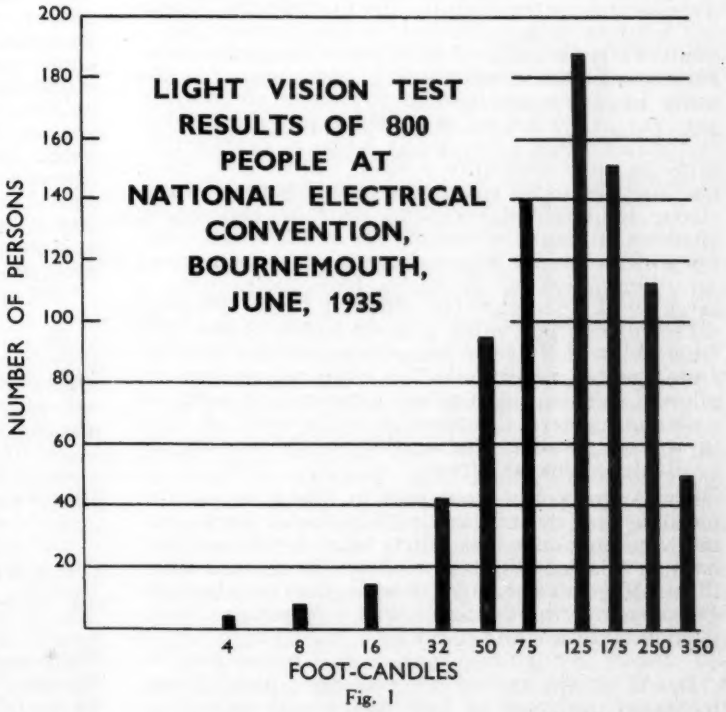

Fig. 1

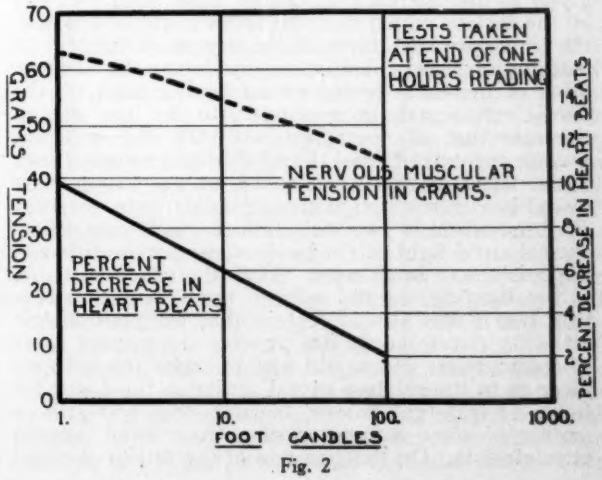

Fig. 2

showed some work of Luckiesh on the question of fatigue, which included the relation of heart beats to various values of illumination.

Mr. T. C. ANGUS (Department of Industrial Physiology, London School of Hygiene and Tropical Medicine) drew attention to a practical development of domestic lighting which, by the success it had already achieved, appeared to confirm the value of one of the author's arguments as to the ill-effects of using high illumination on the working point with comparative darkness behind. In the May, 1934, Transactions of the Illuminating Engineering Society of America was published a specification for a student's lamp designed to allow of long periods of close work with a minimum of eye strain. In the same issue the serious charge was made that 40 per cent. of eye defects in students were attributable to the bad lighting frequently found in studies, dormitories, and fraternity houses. This new lamp obviated the usual conditions in which there was a strong light on the working surface and heavy shadows all round by making use of a 100-watt pearl lamp about twenty inches above the table and giving an illumination of 30 to 40 foot-candles over a large working area. Its diffusing and reflecting arrangements prevented a direct vision of the bulb from below and at the same time, secured freedom from spectral reflection. The large hole in the top allowed sufficient light to reach the ceiling and gave a pleasant general illumination in the room. A lamp to a very similar specification would shortly be available in this country.

Mr. Angus pointed out how in fitters' shops it is usual to find the brilliantly illuminated work-piece in a vice surrounded by a dirty black bench and, perhaps, a "black" blindless window. He showed slides illustrating how this high contrast effect may be mitigated by covering the bench with newspaper and the window with a white blind.

Dr. W. S. STILES, referring to the author's comments on the flood of light which appeared to be given by the mercury discharge lamp, said that one of the factors which must be borne in mind was that the impression we form of the degree of light in an installation was probably largely due to the illumination of the extra-foveal retina, rather than of the foveal retina and the sensitivity to the blue end of the spectrum as compared with the red end was greater for extra-foveal than for foveal vision. Since illumination values were based on the photometric visibility curve which assumes foveal vision, equality of illumination in two installations employing different coloured light might be consistent with different impressions of brightness. As to the practical value of the lighting, we did not yet know how to assess this, but it was almost certain that the photometric visibility curve would not provide the correct basis of comparison. He would like to know the author's view as to the relative visual acuity at the fovea for lights of different colour, because this was still a matter of some difference of opinion even among physiologists. On the question of the fall in contrast sensitivity at high brightness levels dealt with in one of the author's slides, he believed that although such a rise had been found in the measurements of König, Halladay, and in N.P.L. investigations, it might not always occur, owing to the operation of an adaptation factor about which we knew very little. In the course of some further remarks, Dr. Stiles spoke of the problem of deciding how the discrimination of the form of an object, the details of which subtended angles well above the acuity limit, was affected by changes in the acuity limit. In practice mistakes were, in fact, made in perceiving objects very much larger than the threshold limit appropriate to the lighting conditions as determined by special tests. Could this be explained by saying that under practical conditions there was still a threshold value which was much larger than, but which varied in the same general way with, illumination level, etc., as the threshold value determined by laboratory tests. It might be found, however, that the idea of threshold values broke down altogether in such cases, and that other factors not directly related to vision such as the mental attitude of the subject were responsible for the mistakes made. Thus, under practical conditions, vision well above the threshold limit might prove not to be an illumination problem at all.

Dr. G. P. CROWDEN (Department of Industrial Physiology, London School of Hygiene and Tropical Medicine) congratulated Dr. Lythgoe on his most valuable paper, and drew attention to paragraph 10 (3) of the Shops Act, 1934, which reads as follows:—

> "In every part of a shop in which persons are employed about the business of the shop. suitable and sufficient means of lighting shall be provided, and every such part of a shop shall be kept suitably and sufficiently lighted."

He observed that medical officers, faced with the problem of giving effect to this Act, were in difficulties as soon as they tried to define the precise and practical meaning of "suitable" and "sufficient." They must look to research workers like Dr. Lythgoe for some guidance in such matters, and also in regard to visual acuity for different types of illumination, e.g., from daylight corrected lamps about which there existed considerable misconception. In regard to the speeding up of the tile dressing as a result of increased illumination, as referred to by Dr. Lythgoe and commented on by several speakers, he suggested, as a possible explanation, that with improved lighting, the worker had less fear of working quickly, as he could more easily see the tile presses and the danger spots and projections which might injure his hands, and which he took more time and care to avoid under conditions of semi-darkness.

Mr. F. C. SMITH (Gas Light and Coke Company) remarked on the manner in which our ideas of the illumination required for definite tasks had changed during the past few years, and referred to the low orders of illumination which were considered satisfactory in the days of the paraffin oil lamp. He wondered whether the standard of sight was better to-day as a result of the higher illuminations demanded than in the old days, and whether we were

doing right in demanding these relatively high values. On the point mentioned by Dr. Walsh as to adaptation on passing from a brightly illuminated street to one of a very low degree of illumination, he asked the author whether the time to adjust oneself to the altered conditions varied very much as between individuals, as it seemed to him an important point.

Mr. L. E. BUCKELL referred to the view held by many people that considerably higher illuminations than any in use at present might be necessary to avoid ultimate deterioration of eyesight.

He said that this idea was claimed to be based on the physiological fact that the eye had developed under conditions of high illumination and that therefore it was believed that although it could adapt itself to see under lower illuminations it could only do this by increased muscular and nervous effort, which ultimately was harmful not only to the eye but to the whole nervous system.

He had hoped that the author would deal with this point in his paper, and as he had not done so, asked for the author's views as to the truth or otherwise of this theory in his reply to the discussion.

Mr. HOLMES spoke of the connection between motion and vision, and suggested that in reading the eye was in motion; which, perhaps, explained the difference between the 100 foot-candle (Optimum Illumination) figure obtained from an ordinary reading test and the much lower figure obtained when viewing a single letter without any movement of the eye.

Another speaker remarked that as a motorist he often found it more comfortable to drive under less modern conditions of street lighting than under the more modern conditions, which involved specular reflection and seeing objects in silhouette. According to one of the diagrams in the paper the acuity of vision fell off very rapidly as the background was made much brighter than the object, and that might explain to some extent why he did not feel the same absence of nervous strain when driving in brilliantly lighted streets that he did when driving in less brilliantly lighted streets.

Mr. J. M. WALDRAM (General Electric Research Laboratories), speaking of threshold values, asked if it were possible to estimate the relative visibilities of, for example, two objects which were, say, ten or fifty times the threshold contrast or threshold size, or both. That was the question which arose in many problems, but nobody seemed to be able to make any measurements except at the threshold, where it was not possible to see anything. Threshold conditions hardly ever occurred in practice. He had also been very interested in the problem of the ability of the eye to judge absolute values of brightness with different distributions, because it came into some of the photographic work they had been doing. He thought that it was tied up with some of the tricks which the eye seemed to use unconsciously in making judgments. With a large diffusing source of illumination there were no hard shadows, but if there were small bright sources, even if they were out of the line of vision altogether, one was conscious that they were there probably by reason of the shadows. Other people's views on this matter would be of value. It might be that in this matter of the tricks which the eye played in judging distance, form, and speed, and in inferring the nature of the light source, lay the connection between the illuminating engineer and the oculist.

Mr. ACKERLEY asked what was the alteration in the time of seeing with different orders of illumination —e.g., what was the percentage faster time in which one could see with 5 foot-candles as compared with 1 foot-candle, or with 20 foot-candles as compared with 5 foot-candles; also what were the times of adaptation for these respective ranges?

Mr. G. H. WILSON expressed his pleasure that Dr. Lythgoe, in his figure showing the variation in the Fechner fraction, had used " equivalent foot-candles " for the brightness scale; many people found it easier to visualise an equivalent foot-candle rather than a brightness of a candle per unit area. Arising out of the curve for the Fechner fraction, Mr. Wilson drew attention to the fact that the lowest value of the fraction did not occur until a brightness of about three equivalent foot-candles had been reached. Was it not possible, therefore, that in street lighting there would be some improvement in visibility if the street background brightness were as high as three equivalent foot-candles? With this level of brightness, objects of lower contrast would be more visible against the background than at any other level. Mr. Wilson stated that in the best-lighted streets the background brightness was seldom greater than one equivalent foot-candle and he therefore thought it would be valuable to investigate the advantage of increasing this brightness.

Mr. Wilson, commenting on the remark by the author that contrasts outdoors were greater than those indoors, said he wondered whether that was really the case. It was true that outdoor lighting usually came from a very large area and therefore the dark part of objects was smaller in size than in the case of indoor lighting where there were usually one or two isolated sources of light and heavy shadows. Was it a fact, however, that the total contrast range was any greater? This was of some interest to him because at the moment he was rather concerned with the question of true reproduction and representation by photography in which this question of contrast range came in. His colleague, Mr. Hopkinson, was reading a paper on this subject in a few weeks and it would be interesting to have the author's views on that matter. With regard to visual acuity with the modern high pressure discharge lamps, Mr. Wilson understood that such lamps were

being used in industries where it was necessary to see fine details such as in chain making, and the workers spoke very highly of them.

Dr. R. J. LYTHGOE in reply:—Perhaps the most fundamental question raised in the discussion is that of the desirability of using threshold values in experiments with illumination. Drs. Walsh and Stiles and Messrs. Jones and Waldram have asked whether it is sound practice to recommend a particular form of lighting because the size of object recognisable or the perception of the brightness-difference is smallest at that value. On the basis of Dr. Stiles's and the present author's work it is possible to express the visual performance under fixed conditions as an ordinate of a frequency-distribution curve: that is to say under those fixed conditions the observer sees a given size of test-object or a given contrast " a " per cent. of the times. Exterpolating from these values it should be possible to say that the observer will return a value of 99.9 per cent. at some other higher illumination. All our measurements must be in terms of something and in order to evaluate a lighting installation in terms of comfort it would be necessary to use the method of introspection. Under the guidance of a skilled psychologist it might just be possible to grade an observer's likes and dislikes into some sort of scale of measurement.

Mr. Paterson and Mr. Weston have asked whether the improvement of performance in the non-visual operation of tile-pressing when the illumination is raised is not due to psychological factors. My own view is that this is probable, but it is very difficult to prove that a cheerful and happy worker has a larger output. In the laboratory uncomfortable conditions do not lower performance and it is said that with a serious lack of oxygen in the atmosphere, the observer shows no deterioration in performance when he is really trying to do his best. My remarks on tile-pressing were made in the hope of analysing the effects of unfavourable lighting conditions. It might be possible to find out whether the loss of output at low illuminations occurred at the press itself or whether the worker took a longer pause between operations. In this way it might be possible to effect a further analysis of this type of industrial occupation. I feel that Dr. Crowden may be right when he suggests that under higher illuminations the worker is not so fearful for his own safety.

There is a certain amount of evidence that the rate of dark-adaptation is very variable for different persons under laboratory conditions and for adaptation to complete darkness. In answer to the questions of Dr. Walsh and Mr. Smith, I do not know of any figures for adaptation to low levels of brightness from a higher level. It is a piece of work which must be undertaken one day.

The most difficult question of all to answer is that of the effects of different types of illumination on " eye fatigue " and disease of the eye. My own view is that this problem should be attacked rather differently. It is quite certain that very many persons suffer from latent squint and refractive errors. In a farm worker or any person who does not do fine visual work, these defects would pass unnoticed. Under exacting visual conditions these defects become prominent and it is probable that they are also more prominent and liable to give rise to symptoms such as headaches under poor illumination conditions. It seems very probable that the headaches, etc., have a muscular origin, one or more muscles being in overaction to maintain clear vision. In normal persons doing fine close work the continuous contraction of the muscles of accommodation may produce symptoms, but in persons with defective vision working under bad conditions of illuminations I should expect visual symptoms to be prevalent. I gather that this also is the view of Wing-Commander Livingston. If our workers' eyes were examined more carefully, I should expect fewer complaints about the lighting system.

The eye can see over one range of illuminations from 0.00001 to 1 foot-candles, and another equal range from 1 to 10,000 foot-candles. I could not agree with Mr. Buckell that the eye was evolved under high illuminations. The evidence goes to show that man evolved from some marine animal who would need to see in the lower range of illuminations. So far as I know there is no evidence that our much-worked eyes are any worse than those of our ancestors. More people wear glasses nowadays, but that is because modern conditions demand that we should get the best out of our eyes. In answer to Mr. Smith I would say that there is no evidence one way or the other. Lower animals seem to suffer from worse refractive errors than we do. No one would deny that very high brightnesses actually damage the eye as has been shown by Wing-Commander Livingston, but the existing levels of brightness in artificial lighting fall far short of these values.

Mr. Paterson has pointed out that the chief defect of the mercury arc from the visual point of view is that it is minus red rather than plus blue. I would agree that if the red could be supplied by a strontium discharge tube we should have an almost perfect source of cheap artificial light. A little blue goes a long way in experiments on colour: as Dr. Stiles pointed out, blue has a high sensitivity value for the peripheral retina, and this may be a real advantage.

Mr. Ackerley will find some work on the effects of illumination on the speed of vision in the writings of Ferree and Rand. There have been some measurements which indicate that for a fourfold increase in illumination there is a reduction in the time of the act of seeing of 1-50th second; a not inconsiderable reduction. As suggested by Mr. Holmes not only does the perception of a moving object call for a higher illumination, but when two visual factors such as acuity and speed are involved, performance seems to approach its maximum value more slowly, so calling for a higher illumination than when each factor is investigated by itself. There are a bewildering number of factors in any simple visual operation, and Mr. Weston's recent work has gone a long way towards relating some of them.

I have often wondered why the perception of contrast should reach a maximum at so low a value as

3 equivalent foot-candles, and I hope that Dr. Stiles will be able to get some values at illuminations up to 100 equivalent foot-candles. It will probably be necessary to keep the whole visual field in a condition of light adaptation. A determination at higher illuminations is urgently needed. As a motorist I should welcome a brightness level of 3 equivalent foot-candles on the streets at night, and I think Mr. Wilson will find very material benefits from a higher value. The figures of 40 : 1 for the outdoor range of contrasts in daylight, and 100 : 1 by artificial light indoors are often quoted. They are used by photographers, and my own exercises with a portable photometer have tended to confirm them.

Finally Dr. Stiles asks me about visual acuity in light of different wave-length. As he knows there is considerable literature on this subject, and the general conclusion is that visual acuity is maximal in the middle range of the spectrum between yellow and green. There is room for a really thorough re-investigation of the problem, such as Dr. Stiles could undertake. As Sir John Parsons has pointed out, there is no field of science where so many types of scientific worker are involved as there is in the study of the visual processes.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

Forthcoming Events.

Jan. 7th.* **Informal Visit** to the **Demonstration Theatre** of the STRAND ELECTRIC AND ENGINEERING CO. LTD., 27, Floral Street, London, W.C. *(Members wishing to attend should inform Mr. L. G. Applebee at the above address; Tel. Temple Bar 7464)*; **6 p.m.**

Jan. 14th. Mr. F. E. LAMPLOUGH on **Applications of Ultra Violet Light** and **Fluorescence and Phosphorescence** *(Discussion illustrated by Experiments; General Meeting of the Illuminating Engineering Society to be held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1)*; **6.30 p.m.**

Jan. 21st. Mr. A. C. BROWN and Mr. A. L. WHITTENHAM on **"The World's Most Modern Fish Dock."** *(Meeting of the North-Western Area Local Section of the Illuminating Engineering Society at the Engineers' Club, Albert Square, Manchester.)*

Jan. 28th.* Dr. J. W. T. WALSH will deliver an **Introductory Address** at the First Meeting of the Special Section on Photometry of the Illuminating Engineering Society *(Meeting at the Westminster Technical Institute, Vincent Square, London, S.W.1; those interested should inform Mr. K. F. Sawyer, Watson House, Nine Elms Lane, London, S.W.8)*; **6.30 p.m.**

Feb. 4th. **The Annual Dinner** of the Illuminating Engineering Society at the TROCADERO RESTAURANT, Piccadilly Circus, London, S.W.1; **7 for 7.30 p.m.**

*No cards will be issued for these two events.

Copies of this issue of the Transactions are available to those who do not receive them as members at the price of One Shilling and Sixpence each.

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